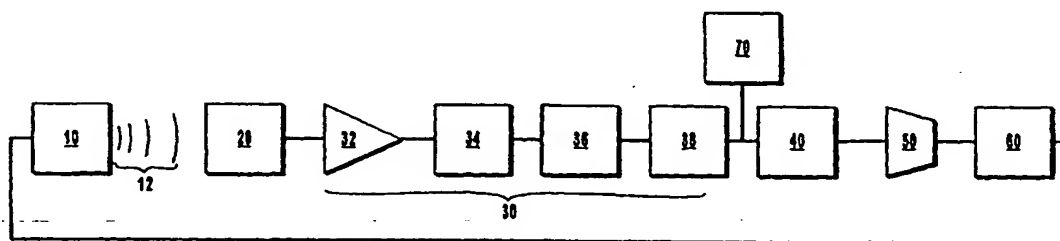




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(54) Title: ULTRASONIC FLUID QUALITY SENSOR SYSTEM**(57) Abstract**

A system for determining the composition of a multiple component fluid as gas or liquid and for determining linear flow comprising a pulse transmitter (10) and pulse receiver (20) used in at least one sing-around circuit that determines the velocity of an audio signal (12) in the multiple component fluid, which velocity is correlatable to a known data base for the multiple component fluid, and where the electronics of a trigger signal circuit (30), amplifier (32), pulser (60), rectifier (34), square wave converter, keep alive circuit (50), alternative pulse width adjuster (40) and gate circuit or digital filter (38) is arranged to determine a signal delay between pulse transmitting and receiving. A method for determining flow in a controlled dynamic fluid supply system uses two of such inventive circuits with independent transmitters and receivers disposed about the fluid of measurement interest, one pair of which transmitter and receiver is set at an angle non-perpendicular to the direction of fluid flow.

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ULTRASONIC FLUID QUALITY SENSOR SYSTEM

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CONTRACTUAL ORIGIN OF THE INVENTION

This invention was made with United States Government support under Contract No. DE-AC07-94ID13223, now Contract No. DE-AC07-99ID13727 awarded by the United States Department of Energy. The United States Government has certain rights
10 in the invention.

RELATED APPLICATION

This application claims priority from provisional application S/N 60/118,561
15 filed February 4, 1999.

BACKGROUND OF THE INVENTION

Field of the Invention

The present invention relates to a system for the quantitative analysis of a fluid that has known components. More particularly, the present invention relates to a system
20 for measuring acoustic pulses in the multiple-component fluid. In particular, the present invention relates to a velocimeter and a method of applying acoustic transmission delay data to empirical correlations with the multiple-component gases.

Relevant Technology

25 Many fluid flow applications require real-time evaluation for various reasons such as fluid quality evaluation and process control. Such real-time evaluation is only complicated where the fluid is a mixture of multiple components. For applications such as in the natural gas industry for gas-fired systems, or in the carburation of a fuel mixture for an internal combustion engine, operating parameters may critically depend
30 upon the ratio of fluid components in relation to each other. Where a correlation exists

for known ratios between multiple components and a given parameter of a particular mixture, such a correlation may be used to facilitate an optimal process that uses the mixture.

One example of the need for real-time evaluation is with natural gas internal combustion engines. Natural gas may have a methane content in a range from about 75% to about 99% methane. This methane composition range can vary between different sources and also the life of the source and the time of year in which the natural gas is removed from the source. Engine knocking is the phenomenon of a pre-ignition of the fuel in the combustion chamber. Knocking has a detrimental and often destructive effect upon the internal combustion engine combustion chamber. It is important therefore in this example of the need for real-time evaluation, to allow an internal combustion engine to be reconfigured in its combustion cycle depending upon the quality of the natural gas that is being supplied.

A well-understood correlation that can be applied to a given process may have a wide variety of applications. Examples thereof include the above-mentioned applications and others such as in the paper and pulp industry, the textile industry, the petroleum industry, materials and chemical testing, effluent monitoring, environmental discharge monitoring, and fluid commodity delivery. All of these applications could all be greatly affected by such a system.

Various problems and challenges occur depending upon the selected multiple-component fluid. For example, gaseous systems have been limited to conventionally lower frequencies because of the extreme attenuation of a high frequency audio signal in the gaseous system. Another difficulty occurs in a gaseous system where the particular geometry confines the distance between a transmitter and a receiver to close proximity. In such a system, there tends to be capacitive coupling between the transmitter and receiver. A capacitive coupling tends to generate a spurious signal that can be misinterpreted by the system as a response signal from the generated acoustic signal.

Another problem occurs where such systems are used around other equipment and machinery. In such an environment, electromagnetic and acoustic

noise may be generated at frequencies that are similar to those designed to be detected in the testing system.

What is needed in the art is a system for quantitatively estimating the make-up of a known multiple-component fluid that overcomes the problems of the prior art. What is needed is a system that overcomes such problems as the unavoidable spurious signal that is generated where capacitive coupling in a gaseous system due to the geometry of the system requires the transmitter and receiver transducers to be in close proximity to each other. What is needed in the art is a system that can operate at high frequencies such that a rapid response and adjustment to the multiple-component fluid can be made for optimal performance of a given process.

Such systems, methods, and apparatuses are disclosed and claimed herein.

SUMMARY AND OBJECTS OF THE INVENTION

The present invention relates to a system for quantitatively determining the components of a known multiple-component fluid.

In one embodiment of the invention, the system uses a "sing-around" circuit that filters out capacitive coupling in a gaseous system. In this embodiment of the present invention, a high-frequency audio signal is generated from a transmitter and detected by a receiver. A high frequency audio signal experiences extreme attenuation in a gaseous system. However, a portion of the audio signal reaches the receiving transducer. The audio signal is converted into an electronic signal that is sent to a triggering system. Due to the extreme attenuation of the audio signal, the electronic signal must be boosted by an amplification circuit sufficient to create a triggering signal.

In the triggering system, the electronic signal is amplified to assist in overcoming the extreme attenuation of the audio signal. Following amplification, the signal is rectified and gathered into a substantially half wave form. Spurious signals that are generated due to capacitive coupling and other causes are filtered out by a gate or digital filter. The digital filter is tuned to anticipate approximately the time period when actual signals should pass therethrough and the digital filter simply eliminates any other signals that come outside the anticipated signal time

window. Following digital filtration, the wave form is converted into a square wave and optionally changed in pulse width to optimize it as a triggering signal. The triggering signal is then ultimately sent to a pulser that instructs the transmitter to generate another audio signal.

5 A "keep-alive" circuit is also provided in the sing-around loop for the occasion where no signal is detected to be cycling within the loop. The keep-alive circuit is configured to look for a pulse coming from upstream in the circuit loop. It looks for a pulse of a particular waveform, namely the square wave, and of a particular pulse width that is characteristic of that which was made of the circuit
10 following digital filtration and conversion into a square wave. Where the anticipated signal is not received within a particular time window, the "keep alive" circuit generates its own signal, directed to the pulser, that instructs the transmitter to generate another audio signal in the direction of the receiver.

 In any event, a pulse signal is generated and directed to the transmitter. At
15 this point, a new audio signal is generated from the transmitter and detected by the receiver. After a number of cycles, the "sing-around" circuit settles down to its designed cycling time. The amount of time required to relay the signal from the receiver around to the transmitter is known. The largest time lapse in the circuit is the time required for the audio signal to bridge the distance between the transmitter
20 and the receiver. As such, the speed of sound in the known multiple-component fluid can be extracted from the total cycling time of the circuit.

 As the components of the multiple-component fluid are known, a database comprising the speed of sound at various component ratios of the known multiple-component fluid may be referred to and an estimate of the precise composition of the
25 multiple-component fluid may be made. The simplest systems comprise binary, or two-component fluids. Two-component fluids generally have a linear or simple non-linear relationship such as the speed of sound as a function of concentration of the two components in the fluid.

 Where the multiple-component fluid is a ternary system, a quaternary system,
30 or greater, additional properties of the multiple-component fluid may need to be tested for determination of the ratios of the individual components. Examples of

additional properties may include heat capacity, electrical conductivity, spectroscopic qualities such as nuclear magnetic resonance, infrared, and others, and optical qualities such as fluid color and index of refraction. Where a multiple-component fluid is being used in a dynamic system that requires a frequent reevaluation of the makeup of the system or greater, preferred tests will be those that have a rapid-evaluation time that is sufficient for the system to be adjusted to optimize operation thereof with the particular multiple-component fluid flowing through it.

It is therefore an object of an embodiment of the present invention to provide a system that overcomes the problems of the prior art. It is also an object of an embodiment of the present invention to provide a system for the evaluation of the quality of a multiple-component fluid as it relates to its usefulness as a fluid commodity.

It is also an object of an embodiment of the present invention to provide a sing-around circuit to evaluate a gaseous fluid that filters all spurious signals.

It is also an object of an embodiment of the present invention to provide a system for the evaluation of a multiple-component fluid that is being used in a dynamic system. It is also an object of an embodiment of the present invention to provide a system for the measurement and control of fluid flow that is being conveyed in a conduit.

~~-----~~ These and other objects and features of the present invention will become more fully apparent from the following description and appended claims, or may be learned by the practice of the invention as set forth hereinafter.

BRIEF DESCRIPTION OF THE DRAWINGS

In order that the manner in which the above-recited and other advantages and objects of the invention are obtained, a more particular description of the invention briefly described above will be rendered by reference to a specific embodiment thereof which is illustrated in the appended drawings. Understanding that these drawings depict only a typical embodiment of the invention and are not therefore to

be considered to be limiting of its scope, the invention will be described and explained with additional specificity and detail through the use of the accompanying drawings in which:

Figure 1a is a block diagram of a sing-around circuit that is part of the inventive system;

Figure 1b is an illustration of the inventive signal processing that corresponds to the sing-around circuit of the present invention;

Figure 2 is an elevational cross-section illustration of one embodiment of the present invention, wherein a pair of circuits evaluate both fluid composition and fluid flow rate;

Figure 3 is a block diagram that illustrates signal processing achieved in the embodiment depicted in Figure 2.

Figure 4 is an illustration of an alternative embodiment of the device depicted in Figure 2, wherein an integral transmitter generates a signal that can be detected by more than one receiver.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

The present invention relates to a system for quantitatively determining the components of a known multiple-component fluid. It is assumed throughout this disclosure that uniform fluid flow in a conduit is being analyzed. However, flow may comprise single-phase or multiple phase laminar or turbulent plug flow, and multiple-phase flow. Preferably the flow regime is single-phase flow.

In a first embodiment of the present invention, the problem of capacitive coupling and its production of a spurious signal is overcome with the inventive system. In some geometries, placement of the transmitter and the receiver must be in such a close proximity that in a gaseous system, the transmitter and the receiver act as capacitor plates. The size of the capacitive charge between two plates is dependent upon the exposed surface areas and the distance therebetween.

Figure 1a is a block diagram illustration of the inventive system. Figure 1b further illustrates the inventive system by illuminating the signal that is being manipulated. The block diagrams in Figure 1b that are positioned immediately

beneath the block diagrams in Figure 1a, illustrate the signal as processed in the respective block diagrams of Figure 1a.

5 A transmitter 10 generates an audio signal 12 that is broadcast in the direction of a receiver 20. Audio signal 12 moves through a medium between transmitter 10 and receiver 20. Typically, the medium is a solid, a liquid, or a gas; preferably it is a gas. Receiver 20 detects audio signal 12 and an electronic signal is generated within receiver 20 as illustrated in Figure 1b.

10 The remainder of the inventive system is a means for determining the signal delay between the transmitter and the receiver. The inventive system includes a high frequency signal as defined below, propagating through a gaseous medium, and the configuration of a trigger circuit 30 that overcomes the problems of the prior art.

The signal is transmitted to an amplifier 32 in order to overcome the likely extreme attenuation of the broadcast signal that occurs between transmitter 10 and receiver 20.

15 Amplified signal 33 is then transmitted to a rectifier 34 to substantially eliminate the sinusoidal nature thereof. A rectified signal 35 is then transmitted to an envelope detection circuit 36 that converts rectified signal 35 into a half wave 37. Half wave 37 is then transmitted to a masking or gate circuit. The masking or gate circuit acts as a digital filter. The inventive system is configured to expect reception
20 of half wave 37 at digital filter 38 within a certain time window. All spurious signals that arrive at digital filter 38 outside the time window, are substantially eliminated thereby. Following the digital filtration of half-wave 37, the signal is transmitted to a pulse width adjuster 40. Pulse width adjuster 40 is placed within the inventive system to provide an adequate triggering signal to cause transmitter 10 to
25 repeat its transmission to receiver 20. Typically, the pulse width of half wave 37 will be inadequate, namely too narrow, to facilitate the triggering of a new pulse from transmitter 10. Therefore, a TTL or square wave 41 is generated at pulse width adjuster 40.

30 The inventive system also uses a "keep-alive" circuit 50 that is configured to send a square wave approximately equivalent to square wave 41 to a pulser 60. Pulser 60 receives either square wave 41 from pulse width adjuster 40 or a similar

square wave from keep alive circuit 50. Pulser 60 then in turn generates a signal that induces transmitter 10 to repeat the cycle.

5 A digital readout 70 is placed somewhere after digital filter 38 in order to provide an observer with information regarding the cycling time of the inventive system. Digital readout 70 may be configured to display a frequency of the total
10 cycling time of the inventive system. The total cycling time of the inventive system is correlatable to different fluid compositions and the respective speeds of sound therein. Digital readout 70 may display a cycling time frequency that, depending upon the medium being tested, will allow the observer to compare the frequency to known binary fluid systems and to arrive at an estimated composition ratio of the components thereof. Alternatively, digital readout 70 may simply relay its information to another system that assists to correlate the fluid's audio transmission characteristics to its composition ratio.

15 After employment of the means for determining the signal delay between the transmitter and the receiver, a means for correlating the signal delay to a database is employed for the multiple-component fluid. In its simplest form, the means for correlating the signal delay to a database includes the decision whether to eliminate the signal processing time between receiver 20 and transmitter 10 from the total cycling time of the inventive circuit or whether to ignore it. Another portion of the
20 means for determining the signal delay between the transmitter and the receiver includes empirical data and digital readout 70.

In a specific embodiment of the present invention, transmitter 10 and receiver
20 are separated by a distance of less than about 10 cm. In this embodiment of the present invention, transmitter 10 and receiver 20 may be spaced apart in a range
25 from about 0.5 cm to about 20 cm and the exposed surface area of each that acts as a capacitive plate is in a range from about 1 cm² to about 20 cm². The surface area of each exposed portion thereof that acts as a capacitor is preferably less than about 10 cm². Capacitance may be created between the two surfaces of transmitter 10 and receiver 20 that are exposed. The creation of a capacitive coupling therebetween
30 is proportional to both the exposed surface area and to the magnitude of the capacitive charge. The placement of transmitter 10 and receiver 20 in much closer

quarters such as a 5 cm separation, a 2 cm separation or a 1 cm separation, even with a smaller exposed surface area therebetween will cause capacitive coupling to occur along with its spurious signal generation.

An example of this application of the present invention is in the carburation of a fuel mixture for an internal combustion engine or in determining the quality of natural gas in a pipeline where the capacitive coupling effect occurs due to both the magnitude of the capacitive charge and the surface areas of transmitter 10 and receiver 20 that are exposed. Transmitter 10 generates a signal in a frequency range between about 100 kHz to about 10 MHz. In this application, where audio signal 12 is transmitted through a gas, attenuation thereof is extreme due to high frequencies. A frequency for a gaseous system is in a range from about 500 KHz to about 5 MHz, preferably about 1 MHz. At this frequency range, attenuation may exceed 50%, may exceed 90%, and may exceed 99.9%.

In order to avoid sending a spurious signal generated by capacitive coupling substantially simultaneously with audio signal 12, audio signal is generated in a pulse width in a range of about 0.1 microseconds to about 5 microseconds. Preferably, the pulse width is in a range from about 1 microsecond to about 3 microseconds, and more preferably about 2 microseconds. Due to the extreme narrowness of the pulse width of audio signal 12, and due to the extreme attenuation of such a high frequency signal in a gaseous medium, reception thereof by receiver 20 is problematic. As such, received signal 21 is amplified in amplifier 32 for a gain between about 100 and about 10,000, preferably 200 and 5,000, and most preferably about 1,000. A variable-gain amplifier may be used to tune the inventive system such that received signal 21 is amplified sufficiently to be further processible. In the gaseous system, the size of the gain in amplifier 32 is generally configured to be directly proportional to the frequency of the audio signal. In this embodiment, the gain is about 1,000, the frequency is about 1 MHz, and the pulse width is about 2 microseconds.

Following the conversion of received signal 21 into amplified signal 33, amplified signal 33 is converted into rectified signal 35. Thereafter, rectified signal 35 is manipulated into a half wave form, into a half wave 37, and directed further.

Half wave 37, whether a spurious signal or a desired signal, is directed through digital filter 38.

As previously explained, a time window during which the desired signal is received is closed to all other signals such as a signal generated due to capacitive coupling between transmitter 10 and receiver 20. Typically, because the pulse width is about 2 microseconds wide, pulse width adjuster 40 is provided to make half wave 37 into square wave 41. Pulse width adjuster 40 is capable of both diminishing the size of half wave 37 or increasing its size. Typically, the pulse width is about 2 microseconds and pulse width adjuster 40 adjusts the size of half wave 37 to be approximately 10 microseconds wide. The advantage to making the pulse width approximately 10 microseconds wide is that the circuit does not accidentally trigger more than once within a preferred time period.

Square wave 41 passes further through the circuit to keep-alive circuit 50. Keep-alive circuit 50 waits for a preferred time period to receive a detected signal and if no signal is received, keep-alive circuit 50 generates its own signal to pulser 60 in order to repeat generation of audio signal 12. In this embodiment, the timing window, or waiting time, is between about 50 and 500 microseconds, preferably about 100 and about 300 microseconds, and most preferably about 200 microseconds.

Square wave 41 or a square wave from keep alive circuit 50 is generated. In any event, a square wave of about 10 microseconds width enters pulser 60 and is of sufficient voltage, amplitude and duration to cause transmitter 10 to repeat the transmission of audio signal 12.

The time delay between the transmission of audio signal 12 and the reception thereof at receiver 20 is significantly larger than all other elapsed time within the circuitry of the inventive system. As such, the elapsed time to process received signal 21 as a part of the entire cycling time of the inventive system may either be disregarded or subtracted. Subtraction of the signal processing time as part of the total elapsed time of each cycle becomes less important as the distance between transmitter 10 and receiver 20 increases. Pulser 60 generates a TTL square wave

voltage spike in a range from about 60 volts to about 220 volts, preferably about 120 volts. In response, transmitter 10 generates a signal that propagates to receiver 20.

Pulser 60 is designed to repeat pulses at a rate between about 10 to about 100 KHz, preferably between about 40 to about 50 KHz. In other words, elapsed time for one cycle between a first pulse and a second pulse is in this kilohertz range. The rate is dependent upon the speed of the audio signal as it propagates through the medium being tested and the distance between transmitter 10 and receiver 20.

Tests were run on the inventive system. For Test 1, the frequency of the circuit was determined in air and was found to be between 31.687 and 31.667 kHz.

The following tests were run on air and on He/N systems. In each test, the frequency was taken from digital readout 70. Tests 1 through 15 were taken a separation between transmitter 10 and receiver 20 of 1 cm. 1 cm herein is taken as equal to 0.3937 inches. Table 1 depicts Tests 2 through 16 for He/N systems.

Table 1

Run 1 @ 1 cm			
Test No.	% He	Temp (degree F)	Frequency (kHz)
2	45	74.1	40.559
3	35	74.9	38.113
4	25	74.6	36.107
5	15	75.2	34.344
6	5	75	32.805
Run 2 @ 1 cm			
7	45	74.6	40.55
8	35	74.9	38.104
9	25	74.8	36.096
10	15	75.3	34.309
11	5	75.1	32.791

5

Run 3 @ 1 cm			
12	45	74.5	40.523
13	35	75	38.097
14	25	74.9	36.11
15	15	75.4	34.329
16	5	75.1	32.8

For Test 17, the frequency of the circuit was determined in air and was found to be between 16.564 and 16.498 kHz. Table 2 depicts Tests 18 through 32 for He/N systems.

10

Table 2

15

Run 1 @ 2cm			
Test No.	% He	Temp (degree F)	Frequency (kHz)
18	45	74.5	21.541
19	35	74.9	20.177
20	25	74.8	19.002
21	15	75	18.038
22	5	75.2	17.15
Run 2 @ 2 cm			
23	45	74.7	21.552
24	35	74.8	20.178
25	25	74.7	18.996
26	15	75	18.04
27	5	75.2	17.159

20

Run 3 @ 2 cm			
28	45	74.7	21.555
29	35	74.7	20.175
30	25	74.4	18.975
31	15	75.1	18.045
32	5	75.1	17.154

For Test 33, the frequency of the circuit was determined in air and was found to be between 11.200 and 11.186 kHz. Table 3 depicts Tests 34 through 48 for He/N systems.

Table 3

Run 1 @ 3 cm			
Test No.	% He	Temp (degree F)	Frequency (kHz)
34	45	74.8	14.697
35	35	74.8	13.716
36	25	74.4	12.922
37	15	75.2	12.227
38	5	75.1	11.628
Run 2 @ 3 cm			
39	45	74.5	14.699
40	35	74.9	13.71
41	25	74.5	12.921
42	15	75.2	12.233
43	5	75.1	11.626

Run 3 @ 3 cm			
44	45	74.5	14.685
45	35	74.9	13.715
46	25	74.6	12.917
47	15	75.2	12.232
48	5	75.2	11.633

5 In all of examples 1 through 48, it was surprisingly discovered that the inventive system was capable of processing a high frequency audio signal in a gas
 10 where it was known that attenuation in a gas at the frequencies contemplated and used would be extreme and significant. Additionally, at the separation distance between transmitter 10 and receiver 20, the problem of capacitive coupling and its generation of a spurious signal was overcome by the conception and reduction to practice of digital filter 38. Data from Tests 1 through 48, in connection with the
 15 inventive system, provide a reliable correlation between the frequency of the sing-around circuit of the present invention and the gas systems tested. As such, the method for determining the composition of a multiple-component fluid was surprisingly successful in spite of the limitations known for such systems in the prior art.

20 In another embodiment of the present invention, the inventive system is used as a duplicate pair of circuits from which the linear flow of the fluid can be determined. Figure 2 is an elevational cross-section view of this embodiment. It can be seen that transmitter 10 and receiver 20 are configured to transmit audio signal 12 substantially perpendicular to the direction of flow V_f of a multiple-component
 25 fluid within a conduit 14. A second system is configured to transmit an oblique-angle audio signal 112 at an angle θ , between a transmitter 110 and a receiver 120. Transmitter 10 and receiver 20 are used in conjunction with transmitter 110 and receiver 120 in order to assist to determine the linear flow rate of the fluid within conduit 14. The speed of audio signal 12 as it passes through the fluid is determined
 30 between transmitter 10 and receiver 20 as set forth above. Because the multiple-

component fluid composition may be presumed to be substantially homogeneous within conduit 14 between transmitter 10 and receiver 20 and between 110 and receiver 120, and because the distances d and d are known, the angled configuration of transmitter 110 and receiver 120 in relation to the direction of flow V_f will cause oblique audio signal 112 to reach receiver 120 earlier than anticipated by a factor of approximately the linear flow rate multiplied by the trigonometric cosine of the angle θ . In the past, calculation of flow velocity by similar methods required dependency upon such variables as system pressure, system temperature, and the composition of the multiple-component fluid. With the inventive method, system pressure, system temperature, and system composition are substantially eliminated as data from the duplicate pair of circuits is compared. A distinct advantage exists in the inventive system where flow calculation is greatly simplified by the elimination of dependency upon the aforementioned variables. Thus, transmitter 10 and receiver 20 provide a baseline, known audio-signal speed in the multiple-component fluid composition. Transmitter 110 and receiver 120 along with the reception of oblique audio signal earlier than anticipated allows for the determination of linear flow within conduit 14. Preferably, angle θ may be 45° or smaller. As angle θ becomes smaller and approaches 0° , the accuracy of measuring linear flow may increase.

Figure 3 is a block diagram that illustrates signal processing achieved in the embodiment depicted in Figure 2. As a means for calculating Doppler shift effect, f_o and f_f are used to arrive at the flow velocity, V_f .

The combination of transmitter 10 and receiver 20 in connection with transmitter 110 and receiver 120 allow for a dynamic control capability for a system wherein the quality of the fluid must be constantly reevaluated and adjustments made therefore in order to achieve optimum system operation. As an example thereof, a natural gas-fired system such as a gas burner for a boiler, a low NO_x burner, a rotary kiln, a gas combustion turbine, or other systems is supplied with natural gas and the inventive system depicted in Figure 2 comprising conduit 14 and transmitters 10, 110 and receivers 20, 120 are positioned before the gas combustion apparatus.

In an alternate embodiment, transmitter 10 and transmitter 110 are merged into an integral unit as transmitter 310, illustrated in Figure 4. Receivers 320, 420, 520, 620 and 720 are multiplexed to accept audio signal 312. Audio signal 312 is broad enough to strike all receivers.

5 The following tests were conducted using the double sing-around circuit system of the present invention to calculate the flow rate of a known multiple-component fluid, namely He/N. Test 49 was conducted with air at about 73.2°F. Data from tests 1, 17, and 32 were used to correlate with Test 49. Air was passed through conduit 14 at a known rate of 20 cuft/hr. Separation between transmitter 10
10 and receiver 20 was about 1.695 inches. The inventive system settled down to a cycling frequency of about 7.833 kHz from which it was determined that oblique-angle audio signal 112 was carried forward to receiver 120 at a rate of about 0.0135 inches per microsecond. By use of a simple trigonometric calculation, the flow rate was found to be about 20 ft³/hr.

15 Tests 50 through 61 were conducted using helium and nitrogen. The gas flow rate was derived from the data in a manner similar to that for the air flow rate Test 49.

Run 1				
Test No.	Gas	Thermocouple Reading (deg. F)	Frequency (kHz)	Gas Flow Rate (CFH)
50	45% He / 55% N	73	10.321	20
51	35% He / 65% N	73	9.628	20
52	25% He / 75% N	73	9.062	20
25 53	15% He / 85% N	74	8.565	20
54	5% He / 95% N	74	8.131	20

5

10

Run 2				
55	45% He / 55% N	73	10.331	20
56	35% He / 65% N	73	9.629	20
57	25% He / 75% N	73	9.058	20
58	15% He / 85% N	73	8.561	20
59	5% He / 95% N	73	8.128	20
Run 3				
60	45% He / 55% N	73.2	10.333	20
61	45% He / 55% N	73.5	10.335 to 10.341	140

Test 61 was carried out at a substantially higher flow rate.

Because the components of the multiple-component fluid are known, and because correlations may be on hand that describe the multiple-component fluids and their quantitative component ratios, the overall flow rate of the gas and a "snap shot" of its quality may be determined with the inventive system in order to optimize the device that uses natural gas combustion. Additionally, where combustion product effluents must be monitored for environmental reasons, gas quality such as a high sulfur content may allow a combustion system to be adjusted in order to minimize the release of undesirable pollutants to the atmosphere.

Distinct advantages exist with the present invention. Evaluation of a multiple-component gas by the inventive method and system is essentially non-intrusive into a container such as conduit 14. Additionally, the "sing-around" circuitry for use in a gaseous system with an audio signal in the megahertz range allows for error band detection. At a high frequency, the error band does not change

substantially if at all such that the inventive system may be used by broadcasting a range of frequencies at different times and any errors or time delays will remain consistent.

5 The present invention may be embodied in other specific forms without departing from its spirit or essential characteristics. The described embodiments are to be considered in all respects only as illustrated and not restrictive. The scope of the invention is, therefore, indicated by the appended claims rather than by the foregoing description. All changes which come within the meaning and range of equivalency of the claims are to be embraced within their scope.

WE CLAIM:

1. A method for determining the composition of a multiple-component fluid comprising:

providing a transmitter and a receiver, separated by a fixed distance,

5 and with a fluid therebetween;

transmitting a first pulse from said transmitter;

receiving said first pulse across said fixed distance to create a receiver signal;

creating a square wave trigger signal;

10 amplifying said receiver signal to create an amplified signal;

rectifying said amplified signal to create a rectified signal;

converting said rectified signal into a square wave;

alternatively adjusting the width of said square wave;

providing a digital filter to restrict spurious signals;

15 using said square wave trigger signal to transmit a second pulse from said transmitter;

determining the signal delay between transmitting and receiving; and

correlating said delay to a data base for said multiple-component fluid.

20

2. A method for determining the composition of multiple-component fluid according to claim 1, wherein said first pulse and said second pulse are audio signals.

3. A method for determining the composition of multiple-component fluid according to claim 1, wherein said fluid is in a vaporous state.

4. A method for determining the composition of a multiple-component fluid according to claim 1, wherein creating a square wave trigger signal further comprises:

amplifying said receiver signal to create an amplified signal;
rectifying said amplified signal to create a rectified signal;
converting said rectified signal into a square wave; and
alternatively adjusting the width of said square wave.

5. A method for determining the composition of a multiple-component fluid according to claim 1, wherein said transmitter and said receiver each have an exposed surface area in a range from about 1 cm² to about 20 cm², and said exposed surface areas are separated by a distance in a range from about 0.5 cm to about 20 cm.

6. A method for determining the composition of a multiple-component fluid according to claim 1, wherein said first pulse is an audio signal in a frequency range from about 100 kHz to about 10 MHz.

7. A method for determining the composition of a multiple-component fluid according to claim 1, wherein said first pulse is an audio signal with a frequency of about 1 MHz.

5 8. A method for determining the composition of a multiple-component fluid according to claim 1, wherein said pulse is an audio signal with an attenuation between said transmitter and said receiver in excess of about 50%.

9. A method for determining the composition of a multiple-component
10 fluid according to claim 1, wherein said pulse has an initial pulse width in a range from about 0.1 microseconds to about 5 microseconds.

10. A method for determining the composition of a multiple-component fluid according to claim 1, wherein said receiver signal is amplified for a gain
15 between about 100 and about 10,000.

11. A method for determining the composition of a multiple-component fluid according to claim 1, wherein said square wave trigger signal has a width of about 10 microseconds.

20

12. A method for determining the composition of a multiple-component fluid according to claim 1, further comprising, providing a keep-alive circuit

between said receiver and said transmitter, said keep-alive circuit having a timing window in a range from about 50 to about 500 microseconds.

13. A method for determining the composition of a multiple-component
5 fluid according to claim 1, wherein said second pulse is generated from a source that has a potential in a range from about 60 volts to about 220 volts.

14. A method for determining the composition of a multiple-component
fluid according to claim 1, wherein elapsed time between said first pulse and said
10 second pulse is measurable in a range from about 10 kHz to about 100 kHz.

15. A method for determining the composition of a multiple-component
fluid according to claim A, wherein said first pulse and said second pulse are audio
signals, wherein said fluid is in a vaporous state, wherein creating a square wave
15 trigger signal further comprises:

amplifying said receiver signal to create an amplified signal;

rectifying said amplified signal to create a rectified signal;

converting said rectified signal into a square wave; and

alternatively adjusting the width of said square wave, wherein said
20 first pulse is an audio signal in a frequency range from about 100 kHz to about 10 MHz, wherein said first pulse and said second pulse experience an attenuation between said transmitter and said receiver in excess of about 50%, wherein said pulse has an initial pulse width in a range from about 0.1

microseconds to about 5 microseconds, wherein said receiver signal is amplified for a gain between about 100 and about 10,000, wherein said square wave trigger signal has a width of about 10 microseconds, wherein said second pulse has a potential in a range from about 60 volts to about 220 volts, and wherein elapsed time between said first pulse and said second pulse is measurable in a range from about 10 kHz to about 100 kHz.

16. A system for determining the composition of a multiple-component fluid comprising:

10 a transmitter and a receiver, said transmitter and receiver being separated by a fixed distance;

a trigger circuit;

means for determining the signal delay between said transmitter and said receiver, wherein said means for determining the signal delay

15 between said transmitter and said receiver has an alternative digital signal filter connected to said trigger circuit; and

means for correlating said signal delay to a data base for said multiple-component fluid, and wherein said receiver, signal amplifier, signal rectifier, signal converter, alternative signal width adjuster, and transmitter

20 are connected in series.

17. A system for determining the composition of a multiple-component fluid according to Claim 16, further comprising means for eliminating an errant signal generated by capacitative coupling between said transmitter and said receiver.

5 18. A system for determining the composition of a multiple-component fluid according to claim 16, wherein said trigger circuit further comprises:

a signal amplifier connected to said receiver;

a signal rectifier connected to said signal amplifier;

a signal converter connected to said signal rectifier; and

10 an alternative signal width adjuster connected to said signal converter.

19. A system for determining the composition of a multiple-component fluid according to claim 16, wherein said multiple-component fluid is a
15 homogeneously mixed gas.

20. A system for determining the composition of a multiple-component fluid according to claim 16, wherein said transmitter and said receiver each have an exposed surface area in a range from about 1 cm² to about 20 cm², and said exposed
20 surface areas are separated by a distance in a range from about 0.5 cm to about 20 cm.

21. A system for determining the composition of a multiple-component fluid according to claim 16, wherein said transmitter generates an audio signal in a frequency range from about 100 kHz to about 10 MHz.

5 22. A system for determining the composition of a multiple-component fluid according to claim 16, wherein said transmitter generates an audio signal with a frequency of about 1 MHz.

23. A system for determining the composition of a multiple-component
10 fluid according to claim 16, wherein said multiple-component fluid is a gas and said transmitter generates an audio signal with an attenuation between said transmitter and said receiver in excess of about 50%.

24. A system for determining the composition of a multiple-component
15 fluid according to claim 16, wherein said transmitter generates a pulse with an initial pulse width in a range from about 0.1 microseconds to about 5 microseconds.

25. A system for determining the composition of a multiple-component
fluid according to claim 16, wherein said trigger circuit has a signal amplifier with
20 a gain between about 100 and about 10,000.

26. A system for determining the composition of a multiple-component fluid according to claim 16, wherein said square wave trigger circuit generates a square wave signal with a width of about 10 microseconds.

5 27. A system for determining the composition of a multiple-component fluid according to claim 16, further comprising a keep-alive circuit disposed between said receiver and said transmitter, said keep-alive circuit having a timing window in a range from about 50 to about 500 microseconds.

10 28. A system for determining the composition of a multiple-component fluid according to claim 16, wherein said second pulse has a potential in a range from about 60 volts to about 220 volts.

15 29. A system for determining the composition of a multiple-component fluid according to claim 16, wherein elapsed time for one cycling of said system is measurable in a range from about 10 kHz to about 100 kHz.

30. A system for determining the composition of a multiple-component fluid according to claim 16, further comprising means for eliminating an errant
20 signal generated by capacitive coupling between said transmitter and said receiver, wherein said trigger circuit further comprises:

a signal amplifier connected to said receiver;

a signal rectified connected to said signal amplifier;

a signal converter connected to said signal rectifier; and
a alternative signal width adjuster connected to said signal converter,
wherein said multiple-component fluid is a homogeneously mixed
gas, wherein said transmitter generates an audio signal in a frequency
5 range from about 100 kHz to about 10 MHz, wherein said transmitter
generates an audio signal with an attenuation between said
transmitter and said receiver in excess of about 50%, wherein said
transmitter generates a pulse with an initial pulse width in a range
from about 0.1 microseconds to about 5 microseconds, wherein said
10 signal amplifier has a gain between about 100 and about 10,000,
wherein said trigger circuit generates a square wave signal with a
width of about 10 microseconds, wherein said pulse has a potential
in a range from about 60 volts to about 220 volts, and wherein
elapsed time for one cycling of said system is measurable in a range
15 from about 10 kHz to about 100 kHz.

31. A method of controlling a dynamic fluid-supply system comprising:
providing a first transmitter and a first receiver separated by first
fixed distance and with a fluid therebetween;
20 transmitting a first pulse from said first transmitter;
receiving said first pulse across said first fixed distance to create a
first receiver signal;
creating a first trigger signal;

using said first trigger signal to transmit a repeat pulse from said first transmitter;

determining the signal delay between said first transmitting and first receiving;

5 providing a second transmitter and a second receiver, separated by a second fixed distance and with said fluid therebetween, wherein said second transmitter and said second receiver are configured at a non-perpendicular angle to flow of said fluid;

transmitting a second pulse from said second transmitter;

10 receiving said second pulse across said second fixed distance to create a second receiver signal;

creating a second trigger signal;

using said second trigger signal to transmit a repeat pulse from said second transmitter;

15 determining the signal delay between said transmitting and said receiving; and

determining the transit-time shift between said second transmitter and said second receiver.

20 32. A method of controlling a dynamic fluid-supply system according to claim 31, wherein said first transmitter and said second transmitter are an integral unit.

33. A method of controlling a dynamic fluid-supply system according to claim 31, wherein transmitting comprises generating an audio signal in a frequency range from about 100 kHz to about 10 MHz, wherein said first pulse and said second pulse experience an attenuation between said transmitter and said receiver in excess of about 50%, wherein said first pulse and said second pulse each have an initial pulse width in a range from about 0.1 microseconds to about 5 microseconds, wherein said receiver signal is amplified for a gain between about 100 and about 10,000, wherein said receiver signal is converted into a square wave trigger signal with a width of about 10 microseconds, wherein said second pulse is generated from a source that has a potential in a range from about 60 volts to about 220 volts, and wherein elapsed time between said first pulse and second pulse is measurable in a range from about 10 kHz to about 100 kHz.

1 / 2

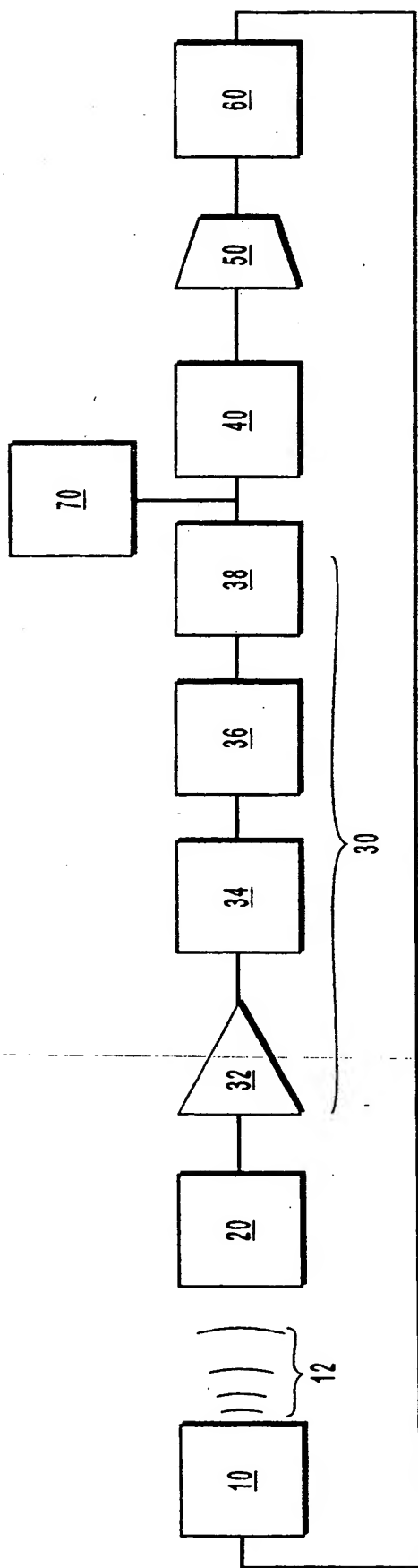


FIG. 1A

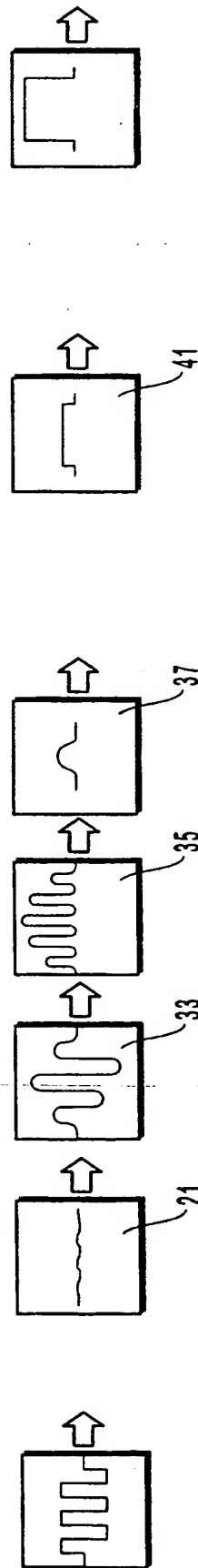


FIG. 1B

2 / 2

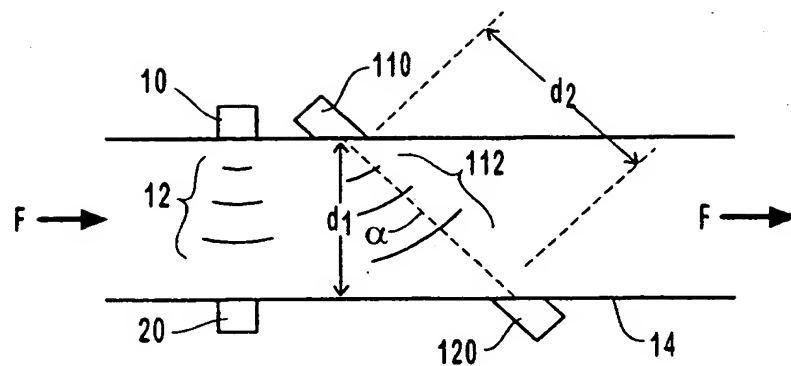


FIG. 2



FIG. 2

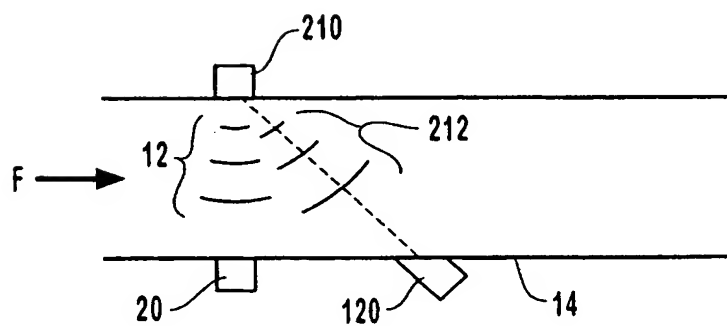


FIG. 4

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US00/02887

A. CLASSIFICATION OF SUBJECT MATTER

IPC(7) : Please See Extra Sheet.

US CL : 073/61.45, 61.41, 24.01, 24.04, 599, 624; 324/464, 453

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 073/61.45, 61.41, 61.49, 64.56, 64.54, 61.59, 592, 628, 24.01, 24.04, 599, 624, 609, 53.01; 324/464, 453, 71.10, 76.13

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
NoneElectronic data base consulted during the international search (name of data base and, where practicable, search terms used)
Please See Extra Sheet.**C. DOCUMENTS CONSIDERED TO BE RELEVANT**

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 5,700,952 A (ANDERSEN) 23 December 1997 (23-12-1997), see entire document.	1-2,4-14, 16-18, 20-22, 24-29
A	US 5,767,409 A (YAMAGUCHI) 16 June 1998 (16-06-1998), see entire document.	1-29
A	US 5,559,292 A (HULL et al.) 24 September 1996 (24-09-1996), see entire document.	1-33
A	US 5,170,667 A (TAKEUCHI et al.) 15 December 1992 (15-12-1992), see entire document.	1-2, 4-14, 16-18, 20-22, 24-29
A	US 5,191,795 A (FELLINGHAM et al.) 09 March 1993 (09-03-1993), see entire document.	1-29

☒ Further documents are listed in the continuation of Box C.☐ See patent family annex.

* Special categories of cited documents:	"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"A" document defining the general state of the art which is not considered to be of particular relevance	"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"E" earlier document published on or after the international filing date	"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	"&" document member of the same patent family
"O" document referring to an oral disclosure, use, exhibition or other means	
"P" document published prior to the international filing date but later than the priority date claimed	

Date of the actual completion of the international search

21 APRIL 2000

Date of mailing of the international search report

26 MAY 2000

Name and mailing address of the ISA/US
Commissioner of Patents and Trademarks
Box PCT
Washington, D.C. 20231

Facsimile No. (703) 305-3230

Authorized officer

DAVID JOHN WIGGINS

Telephone No. (703) 305-4884

International application No.
PCT/US00/02887

International application No.
PCT/US00/02887

[illegible]

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US00/02887

Box I Observations where certain claims were found unsearchable (Continuation of item 1 of first sheet)

This international report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority; namely:
2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:
3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box II Observations where unity of invention is lacking (Continuation of item 2 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

Please See Extra Sheet.

1. ☒ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.
2. ☐ As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.
3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:
4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

☐
☒

The additional search fees were accompanied by the applicant's protest.

No protest accompanied the payment of additional search fees.

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US00/02887

A. CLASSIFICATION OF SUBJECT MATTER:
IPC (7):

G01N 07/00, 29/02, 22/04, 31/00, 09/24; G01S 03/82

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US00/02887

B. FIELDS SEARCHED

Electronic data bases consulted (Name of data base and where practicable terms used):

USPTO APS STN/CAS search terms: transmitter; receiver; pulse or burst or waves; acoustic, audio or sonic; trigger, gate or synchronize; amplifier; rectifier; converter; width or bandwidth or period or duty cycle; composition or identification; gas, fluid or liquid; control or regulate; sound source or transducer; flow and concentration in fluid supply or fluid input;

BOX II. OBSERVATIONS WHERE UNITY OF INVENTION WAS LACKING

This ISA found multiple inventions as follows:

claims 1 meet

Group I, claims 1-2, 4-14, 16-18, 20-22 and 24-29, drawn to a method for determining the composition of a multiple-component fluid via signal transmission/delay of first and second pulses from a transmitter and receiver.

Group II, claims 3, 15, 19, 23 and 30, drawn to a method for determining the composition of a multiple-component gas or vapor via signal transmission/delay of first and second pulses from a transmitter and receiver (where it emphasized that the liquid phase of a substance often has vastly different properties and thermodynamic behaviors from those manifested by the gaseous phase: e.g. heat capacity, density, electrical or thermal conductivity, compressibility, dielectric constant, magnetic susceptibility, etc.).

Group III, claims 31-33, drawn to a method for controlling a dynamic fluid supply system via signal transmission/delay of first and second pulses from each of two pairs "of transmitter and receiver" placed about the fluid and/or flowpath. The inventions listed as Groups I and II do not relate to a single inventive concept under PCT Rule 13.1 because, under PCT Rule 13.2, they lack the same or corresponding special technical features for the following reasons: The fluid investigating and identifying category of method inventions includes resolving a liquid mixture, for which different chemical & physical properties are measured and different response behaviors to stimuli are observed so that different detector types become necessary from those properties, behaviors and detectors found adequate for studying any gaseous phase mixture. Also, a further search of additional classes/subclasses along with an extended classification into more prior art fields is judged to become both feasible and mandatory for the case of the Group I fluid or liquid invention as compared to the Group II vapor invention; finally, a further step such as a pyrolyzer, evaporator, cold condenser or chemical reactor may be necessary in order to convert, transform or generate such a vapor phase with its attendant vapor pressure from the initial fluid or liquid phase. Also, it is noted that not only do the attenuations and sound speeds differ appreciably between air and liquids, but that some high frequency acoustic waves do not even pass thru air (or gas bubbles) due to impedance mismatch, while such same frequencies will pass readily thru liquid media with slight energy losses.

The inventions listed as Groups I and III do not relate to a single inventive concept under PCT Rule 13.1 because, under PCT Rule 13.2, they lack the same or corresponding special technical features for the following reasons: A method of controlling a dynamic fluid supply system is deemed to be considerably different from the purpose of a similar method for identifying or determining composition of a multiple component fluid, since the act of dynamically controlling the fluid input or fluid supply as a function of time may be seen to include flow, flow rate, fluid content or additives, fluid pressure, fluid temperature, salinity or sweetness, purity, direction or restriction (e.g. valves, pumps), as well as making any changes to its composition.